PUTTING RESEARCH TO WORK **BRIEF**

# Creating Durable Pavement with Furnace Slag Concrete

Federally funded highway projects require the performing agency to consider recycled materials as an alternative cementitious material in cement concrete pavement construction. Ground granulated blast furnace slag, a steel manufacturing by-product approved by the U.S. Environmental Protection Agency for such use, warrants consideration for use in Wisconsin concrete pavements. In addition to saving space in landfills, using recycled materials such as GGBFS reduces concrete permeability, which improves long-term pavement durability.

## What's the Problem?

GGBFS has produced mixed results in Wisconsin rigid pavements. Experts do not yet understand why at times it works well and at others poorly. Research suggests the material lengthens the curing period required for concrete pavements to reach sufficient strength to open to traffic. In cold weather, GGBFS concrete requires even more curing time, rendering the cured concrete more susceptible to scaling (flaking) caused by repeated application of deicing chemicals. Longer curing periods may ultimately yield stronger concrete pavement, although research is mixed on this point.

## Research Objectives

Researchers aimed to quantify the strength development and durability of GGBFS over a range of cement brands, aggregates and curing conditions typical in Wisconsin. The most comprehensive investigation of GGBFS concrete performance to date, this research sought to identify curing conditions necessary for GGBFS concrete to reach traffic-opening strength, and to determine the optimal combination of slag level and curing method to achieve acceptable deicer scaling resistance.

## Methodology

Investigators' tasks included:

• Performing a literature search and surveying other Midwest DOTs about their experiences with GGBFS, with an eye toward potential field and performance problems.

• Monitoring the variability of GGBFS composition, based on material delivered by one producer to a ready-mix plant.

• Measuring air-dry shrinkage, hardened air void content, and compressive strength of four different brands of portland cement in 30 mixes varying according to brand, curing temperature, GGBFS replacement level (0%, 30% and 50%), and aggregate type.

• Testing deicer scaling of two cement brands in 13 mixes with four curing methods, employing mix variables similar to those used in air void and strength tests.

## Results

GGBFS performance varied significantly among different combinations of slag, cement, aggregate, and curing practices. Certain combinations can produce strong and durable concrete; however, the outcome depends on a combination of chemical and production factors whose differences may not be readily apparent. With attention to these factors, GGBFS can be used at a 30% cement replacement level to produce stable concrete pavement.

Compared with curing periods for ordinary portland cement concrete, test concrete formulated with 30% slag content took at least twice as long to reach WisDOT's required traffic-opening strength of 3,000 pounds per square inch. With variations depending on aggregate type—limestone coarse aggre-

**Investigator**

*"We shouldn't expect concrete made with slag to perform exactly the same as ordinary concrete. This research helped sort out when we have an advantage and when we don't."*

**–Steven Cramer**
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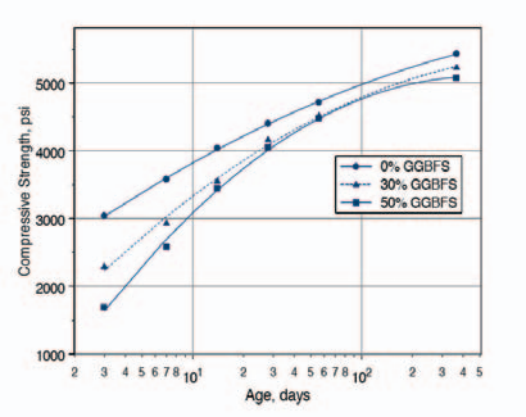


In this study, concrete formulated with 30% GGBFS took an average of 7 days to reach traffic-opening strength of 3,000 psi, compared with 3 days for ordinary cement concrete and 9 days for concrete made with 50% GGBFS. At 1 year, the strengths of all three concretes tended to converge (Fig. 17, page 32 of final report).

gates generally took about 10% less time than igneous—the required curing periods observed were:

- 70 degrees F: 0% GGBFS, 3–5 days; 30% GGBFS, 4–13 days; 50% GGBFS, 6–16 days
- 40 degrees F: 0% GGBFS, 11–18 days; 30% GGBFS, 20–40 days; 50% GGBFS, 31–49 days

Test concrete was formulated with Grade 100 slag; subsequent research using Grade 120 slag has yielded better results. In addition, a water-to-cement ratio of 0.45 was used for all test concrete; concrete with a 0.40 ratio will take slightly less time to reach 3,000 psi under the same conditions.

The primary factor in the deicer scaling test results was the level of GGBFS content, combined with the curing method and cement brand used. Surprisingly, the use of resin and wax curing compounds did not significantly improve scaling performance, and in one case appeared to worsen scaling. Doubling the curing time yielded little improvement in scaling. After 50 freeze-thaw cycles:

- At 0% GGBFS, the test concrete generally exhibited an acceptable amount of scaling, with moist curing the most effective method.
- At 30% GGBFS, the concrete showed good to unacceptable levels of scaling; the most effective curing method varied with the cement brand.
- At 50% GGBFS, scaling was generally greater, and more likely to fall in the unacceptable range. Air-dry curing was the best method.

## Implementation and Benefits

Researchers concluded that in Wisconsin, GGBFS can effectively replace up to 30% of the cement in concrete pavement when combined with the mix-specific curing practices identified in this study. GGBFS should be used at temperatures no lower than 40 degrees F.

Recycled materials such as GGBFS cost slightly less than portland cement, and by decreasing permeability and improving long-term durability, lead to lower life-cycle pavement costs as well.

## Further Research

Research suggests that concretes made with GGBFS may be more susceptible to scaling because the slag causes an increase in carbonation at the concrete's surface during initial curing. Researchers recommend further study of this chemical reaction; understanding and controlling it could significantly improve the scaling performance of GGBFS concrete.

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*This brief summarizes Project 0092-02-14a, "Effects of Ground Granulated Blast Furnace Slag in Portland Cement Concrete," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research, Development & Technology Transfer Program, 4802 Sheboygan Ave., Madison, WI 53707.*

*Nina McLawhorn, Research Administrator*

**Project Manager**

***"By limiting permeability, blast furnace slag gives you an improvement in long-term durability. It's a good option for warm-weather work."***

**–Jim Parry**
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